# MINIMIZATION OF DEFECTS IN ALUMINIUM ALLOY CASTINGS USING SQC

A Thesis Submitted to

**National Institute of Technology, Rourkela**

In Partial fulfillment of the requirement for the degree of

Bachelor of Technology

in

Mechanical Engineering

By


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**Department of Mechanical Engineering**

**National Institute of Technology**

**Rourkela -769 008 (India)**


**2013**

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**Rourkela**

# CERTIFICATE

This is to certify that the thesis entitled "**MINIMIZATION OF DEFECTS IN ALUMINIUM ALLOY CASTINGS USING SQC**" submitted to the National Institute of Technology, Rourkela by KUSAMPUDI NAVYANTH, Roll No. **109ME0393** for the award of the Degree of **Bachelor of Technology** in Mechanical Engineering is a record of bona fide research work carried out by him under my supervision and guidance. The results presented in this thesis has not been, to the best of my knowledge, submitted to any other University or Institute for the award of any degree or diploma.

The thesis, in my opinion, has reached the standards fulfilling the requirement for the award of the degree of **Bachelor of technology** in accordance with regulations of the Institute.

Supervisor

Prof. SAROJ KUMAR PATEL

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# ABSTRACT

In the present world with the increasing use of Aluminium alloy wheels in automotive industry the Aluminium foundry industry had to focus on the quality of the products. The quality of a foundry industry can be increased by minimizing the casting defects during production.

Aim of the current study is to study the production line of an aluminum alloy wheel manufacturing industry and to improve the quality of production using quality control tools. This study shows the systematic approach to find the root cause of a major defects in aluminium castings using defect diagnostic approach as well as cause and effect diagram. Casting defect analysis is carried out using techniques like historical data analysis, cause-effect diagrams, design of experiments and root cause analysis. Data from X-ray inspection (Radiographic Inspection) have been collected along with the production parameter data. Using check sheets data has been collected and all the defects have been studied. Using Pareto chart major defects in the aluminium castings were noted. The major defects for the rejections during production were identified as shrinkages, inclusions, porosity/gas holes and cracks. Each defect is studied thoroughly and the possible causes for the defects are shown in Fishbone Diagrams (Cause Effect Diagrams). As the shrinkages mainly occur due to lack of feedability during the fluid flow the stalk changing frequency is noted along with the shrinkages defects and a relation is drawn between them. As hydrogen forms gas holes and porosity in the aluminium castings the amount of hydrogen present in the molten metal is studied by finding specific gravity of the samples collected. The molten metal temperature effects the amount of the hydrogen absorbed by it. .So the effect of molten metal temperature on the specific gravity of the sample collected have been shown in a graph and the optimum value for molten metal temperature was found out.

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# 1. INTRODUCTION

## 1.1 Low Pressure Die Casting

Aluminium alloy wheels are manufactured through low pressure die casting method. It has been lately developed to enable the production of castings that are flawless, have very thin sections, and register a yield approaching even in metals such as aluminum and magnesium. The mould which is made in the metal (usually cast iron/ die steel) is filled by upward displacement of molten metal from a sealed melting pot or bath. This displacement is effected by applying relatively low pressure of dry air (0.5 ~ 1.0 kg/mm2) on the surface of molten metal in the bath. The pressure causes the metal to rise through a central Ceramic riser tube into the die cavity. The dies are provided ample venting to allow escape of air, the pressure is maintained till the metal is solidified ; then it is released enabling the excess liquid metal to drain down the connecting tube back in to the bath. Since this system of upward filling requires no runners and risers, there is rarely any wastage of metal. As positive pressure maintained to force the metal to fill the recesses and cavities, casting with excellent surface quality, finish and soundness are produced. Low pressure on the metal is completely eliminates turbulence and air aspiration.

**1.2 Al alloy Wheel Production Process:** It consists of the following steps:

- ✓ Melting of Al Alloy
- ✓ Degassing Process
- ✓ Low Pressure Die Casting
- ✓ Solidification of Al Alloy
- ✓ X-Ray Inspection

These steps are also shown in Figure 1.1.

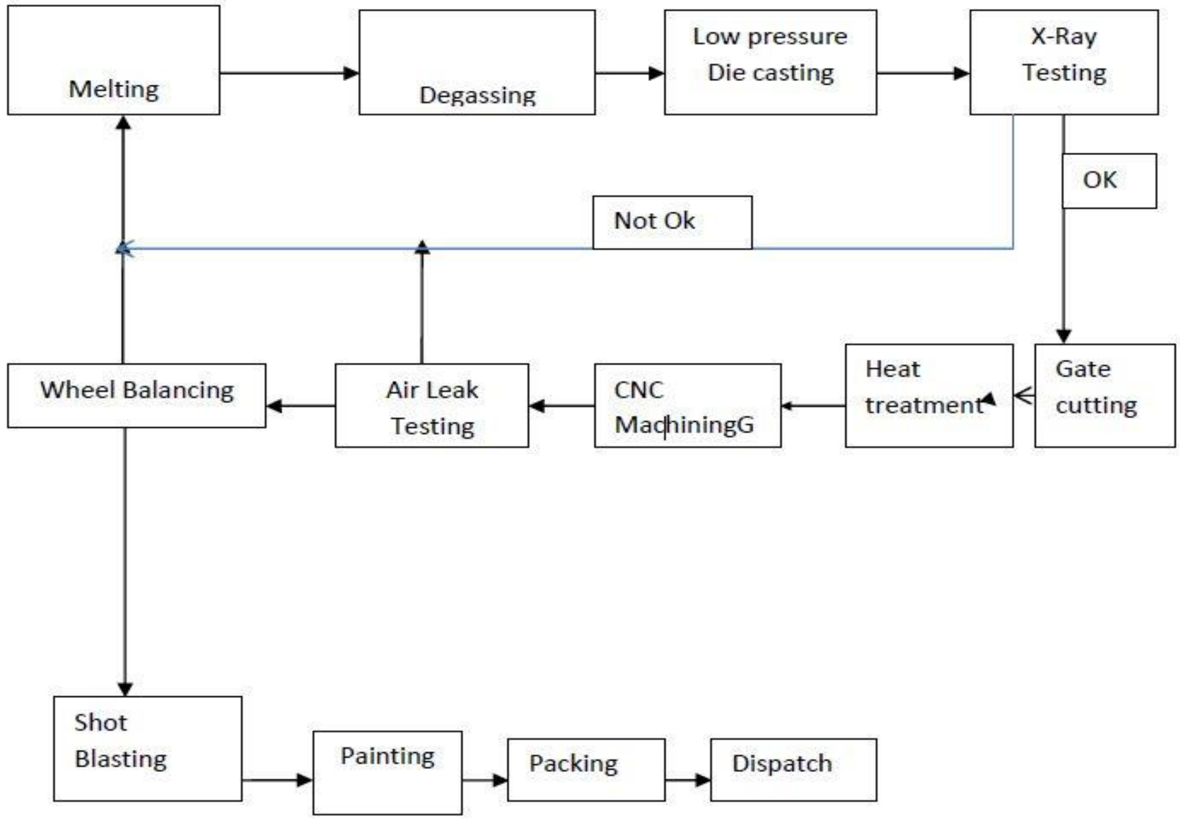


**Figure 1.1.** Process flow diagram for manufacturing of Al alloy wheel

# 2. LITERATURE SURVEY

## 2.1 Statistical Process Control

SPC monitors specified quality characteristics of a product or service so as to detect whether the process has changed in a way that will affect product quality and to measure the current quality of products or services. Using control charts control is maintained. The charts have upper and lower control limits and the process is in control if sample measurements are between the limits current study uses the 7 quality control tools to improve the quality of the product by minimizing the defects [1].

The most successful SPC tool is the control chart, originally developed by Walter Shewhart in the early 1920s. A control chart helps to record data so that we can see when an unusual event, e.g., a very high or low observation compared with typical process performance, occurs. Control charts distinguish between two types of process variation.

1. Common cause variation: Intrinsic to the process and will always be present.
2. Special cause variation: It stems from external sources and indicates that the process is out of control.

Many SPC techniques have been rediscovered in recent years like six sigma control. By integrating SPC with engineering process control (EPC) tools, which regularly change process inputs performance can be increased.

## 2.2 The 7 QC Tools

The 7 QC Tools are simple statistical tools used for data analysis and problem solving [2].

The following are the 7 QC Tools

1. Process Flow Diagram
2. Cause and Effect (Fishbone) Diagram
3. Control Charts
4. Check Sheet
5. Pareto Diagram
6. Scatter Plot
7. Histogram

**Process Flow Diagram**

It gives brief information about the relationships between the process units. It also provides knowledge about the process and identifies the process flow and interaction between the process steps. Potential control points during operation can also be identified using process flow diagram.

**Fishbone Diagram**

Once a defect, error, or problem has been identified and isolated for further study, it is necessary to begin to analyze potential causes of this undesirable effect. After identifying problem, causes for the problem should be identified. In situations like these where causes are obvious or not, the fishbone diagram (Cause effect diagram) is a useful in finding potential causes .By using Fish bone diagram, all contributing factors and their relationship with the defects are displayed and it identifies problem. So it is easy to know where data can be collected and analyzed.

## Control Chart Analysis

Control chart analysis helps in the following ways

1. It helps in monitoring quality in the process
2. To detect nonrandom variability of the process
3. To identify assignable causes

   The chart contains three horizontal lines

   **CL:** Control limit (Mean Line)

   **UCL:** Upper control limit

   **LCL:** Lower control limit

The process is assumed to be in-control as long as the points that are plotted are within control limits, and no need to take necessary action. If a point that plots outside of the control limits we assume that the process is out of control and to take corrective action to eliminate the assignable cause. Control charts provide reducing variability and monitoring performance over time. Trends and out of control conditions are immediately detected by using control charts.

## Check Sheets

Check Sheets are necessary to collect either historical or current operating data about the process under investigation. The check sheet is for collecting the data of defects that occur during castings. Using check sheets data collection and analysis is easy. It also spots problem areas by frequency of location, type or cause of the defect.

**The Pareto Diagram**

Pareto diagram is a tool that arranges items in the order of the magnitude of their contribution. It identifies a few items exerting maximum influence. Pareto diagram is used in SPC and quality improvement for

1. Prioritizing projects for improvement
2. Prioritizing setting up of corrective action teams to solve problems
3. Identifying products on which most complaints are received
4. Identifying the nature of complaints occurring most often
5. Identifying most frequent causes for rejections or for other similar purposes.

**Scatter Plot**

For identifying a potential relationship between two variables Scatter Plot is used. Data is collected in pairs on the two variables, as (x, y), Then y values are plotted against the corresponding x. The relationship between the two variables can be known through the shape of the scatter plot. By using this plot, a positive, negative or no relationship between variables can be detected.

**Histogram**

It represents a visual display of data Observed frequencies versus the number of defects are given in this histogram. The height of the each bar is equal to the frequency occurrence of the defects. The shape of histogram shows the nature of the distribution of the data. On this display, the central tendency (average) and variability are seen. And also, specification limits can be used to display the capability of the process.

# 3. METHODOLOGY

## 3.1 Defect Diagnostic Approach

Defect analysis in casting defects is carried out using techniques like

1. Historical data analysis
2. Cause-effect diagrams
3. Design of experiments and
4. Root cause analysis

- Identifying the casting defect correctly is the first step in the defect analysis [3].
- Then the identification of the sources of the defect is to be made.
- By taking the necessary corrective remedial actions defects can be controlled.
- Implementation of wrong remedial actions makes the problem complicated and severe.
- The major rejected aluminium alloy wheel castings was analyzed using "Defect diagnostic approach" as shown in Figure 3.1.

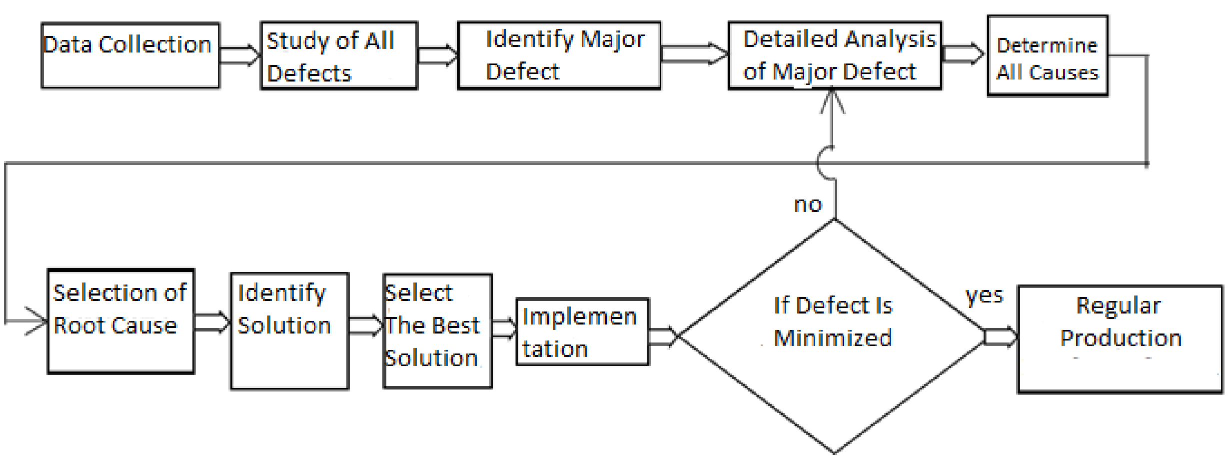


**Figure 3.1.** Defect diagnostic approach [3]

# 4. ANALYSIS

## 4.1 Historical Data Analysis

To find the rejections in castings, data for occurrence of defects for one year was collected from one of leading Al alloy wheel casting industry. Using historical data analysis [2], check sheets have been prepared which helps to identify occurrence defects in aluminium alloy castings. Using check sheets data collection is simple and it also helps in spotting problem areas by frequency of location, cause and type of defects. The details are shown in Table 4.1.

**Table 4.1.** Rejections in casting

| DEFECT | REJECTED QUANTITY | cum % | DEFECT | REJECTED QUANTITY | cum % |
|---|---|---|---|---|---|
| SHRINKAGE | 4078 | 39 | MISMATCH | 84 | 97 |
| POROSITY | 2610 | 64 | GRINDING SHADE | 69 | 98 |
| CRACK | 1410 | 77 | HALF CYCLE | 51 | 98 |
| INCLUSION | 984 | 86 | BELOW RANGE | 46 | 99 |
| UNFILLING | 413 | 90 | EJECTOR PIN DEPRESSION | 42 | 99 |
| PROFILE DAMAGE | 194 | 92 | DENTS | 35 | 100 |
| DISTORTION | 181 | 94 | ABOVE RANGE | 22 | 100 |
| METAL STICKING | 155 | 95 | MESH | 12 | 100 |
| GAS HOLE | 122 | 97 | WITHOUT MESH | 5 | 100 |

### 4.1.1 Pareto Diagram for Defects

Using the data collected for different casting defects pareto diagram have been drawn as shown in Figure 4.1.

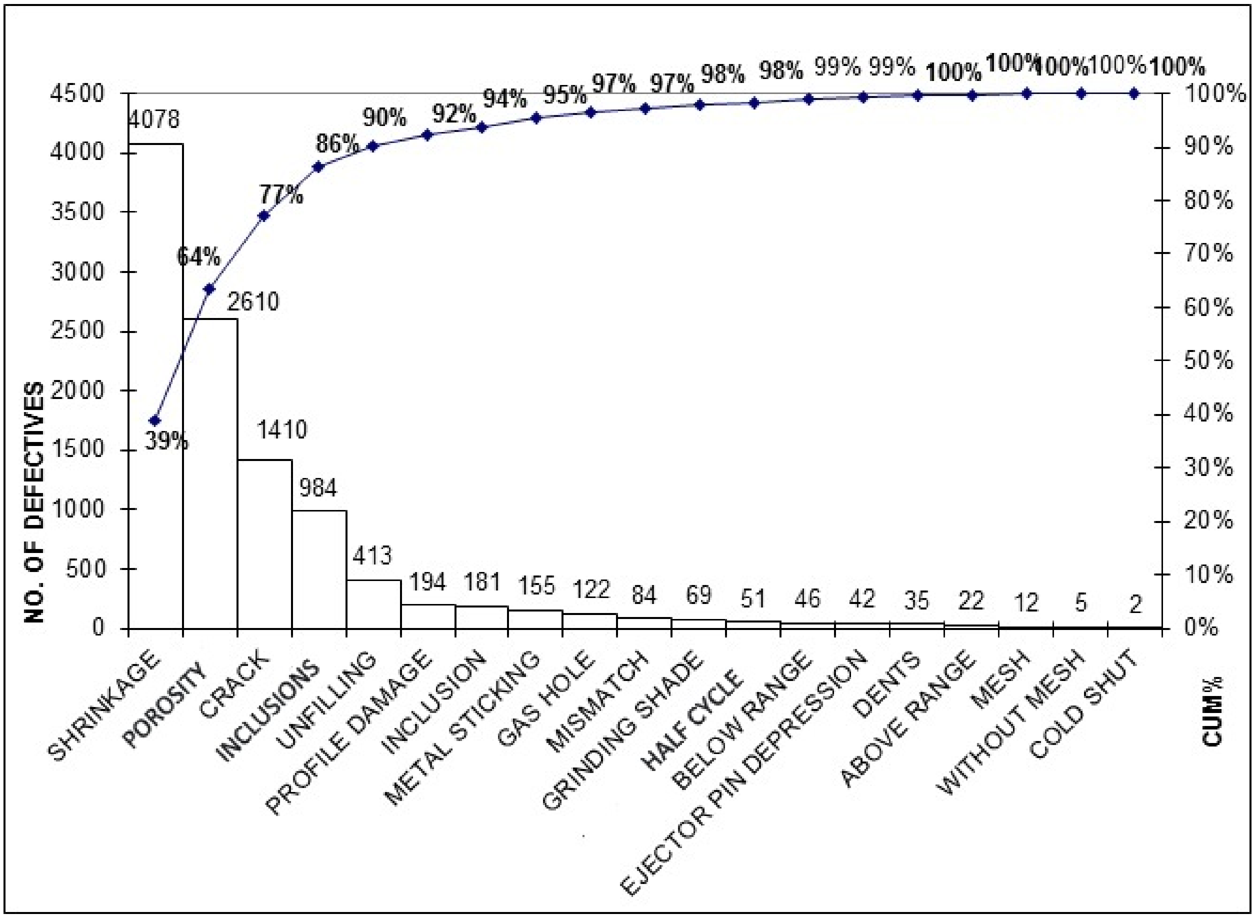


**Figure 4.1.** Pareto chart of rejections of Al alloy wheels for one year

Using pareto chart shown in Figure 4.1, we can conclude that the major causes for the rejections in Al alloy wheel castings were due to 1) Shrinkages 2) Air leak 3) Crack 4) Inclusions etc. [4].

## 4.2 DETAILED ANALYSIS OF THE MAJOR DEFECT-SHRINKAGES

### 4.2.1 Shrinkages

The following points describe how shrinkages occur in castings

- Shrinkage occurs during solidification as a result of volumetric differences between liquid and solid state. For most aluminum alloys, shrinkage during solidification is about 6% by volume [6].
- Lack of adequate feeding during casting process is the main reason for shrinkage defects.
- Shrinkage is a form of discontinuity that appears as dark spots on the radiograph.
- It assumes various forms, but in all cases it occurs because the metal in molten state shrinks as it solidifies, in all portions of the final casting [7].
- By making sure that the volume of the casting is adequately fed by risers, Shrinkage defects can be avoided.
- By a number of characteristics on radiograph, various forms of shrinkages can be recognized.
- Types of shrinkages [5]

  (1) Cavity

  (2) Dendritic

  (3) Filamentary

  (4) Sponge types

**Shrinkage Cavity**

The following points explain how shrinkage cavity occurs in castings

- It appears in areas with distinct jagged boundaries.
- When metal solidifies between two original streams of melt coming from opposite directions to join a common front, cavity shrinkage occurs as shown in Figure 4.2.
- It usually occurs at a time when the melt has almost reached solidification temperature and there is no source of supplementary liquid to feed possible cavities.

**Dendritic Shrinkage**

This type of shrinkage can be identified by seeing distribution of very fine lines or small elongated cavities that may differ in density and are usually unconnected as shown in Figure 4.3.

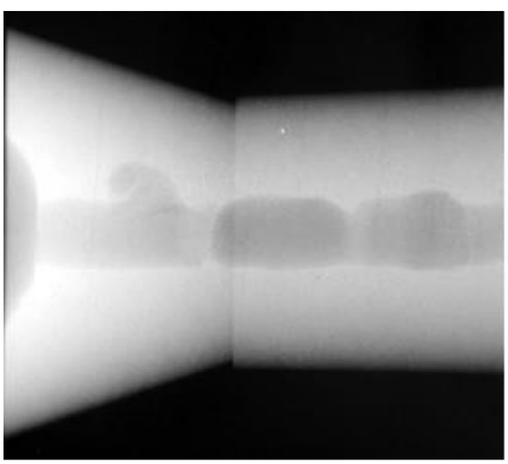

**Figure 4.2.** Shrinkage cavity [5]

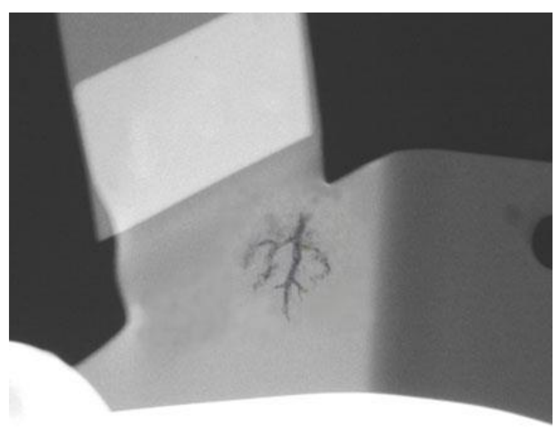

**Figure 4.3.** Dendritic shrinkage [5]

### Filamentary Shrinkage

This type of shrinkage usually occurs as a continuous structure of connected lines of

1. Variable length
2. Variable width
3. Variable density

### Sponge Shrinkage

- Sponge shrinkage can be identified from areas of lacy texture with diffuse outlines as shown in Figure 4.4.
- It may be dendritic or filamentary shrinkage.

Filamentary sponge shrinkage appears more blurred as it is projected through the relatively thick coating between the discontinuities and the film surface.

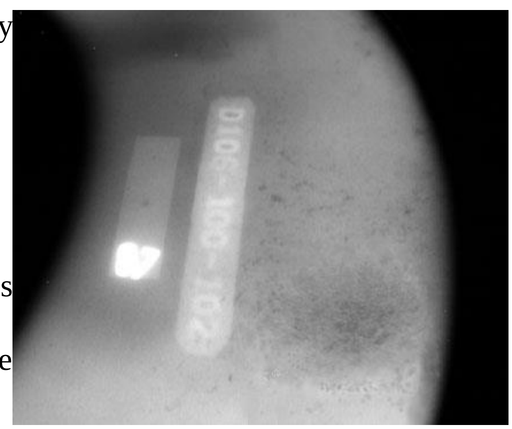

**Figure 4.4.** Sponge shrinkage [5]

### 4.2.2 Fish Bone Diagram for Shrinkages

Fish bone diagram helps in following ways

- Once a defect has been identified, potential causes of this undesirable effect has to be analyzed.
- Fishbone Diagram (Cause Effect Diagram) is a useful tool in finding potential causes. By using this fishbone diagram, all contributing factors of defects and their relationship are displayed in a place.
- It identifies areas of problem where data can be collected and analyzed.
- The fish bone diagram for shrinkages is shown in Figure 4.5.

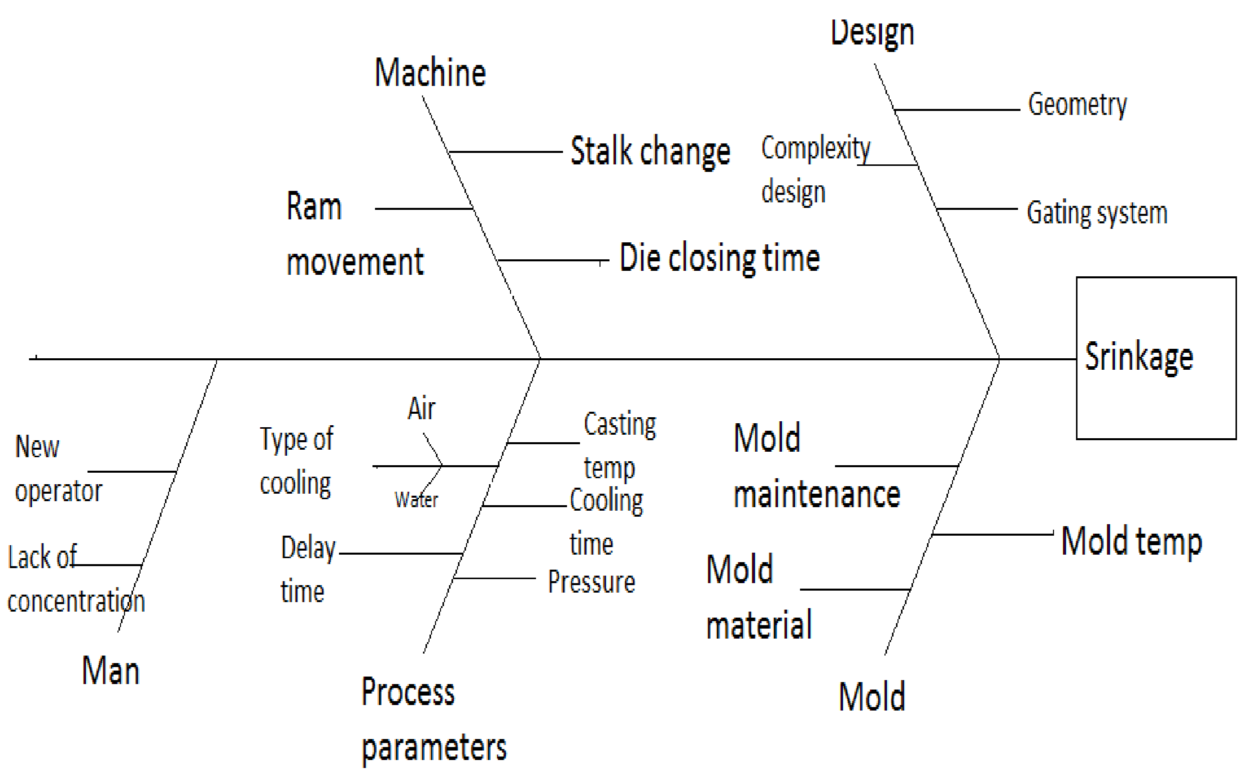


**Figure 4.5.** Fish bone diagram for shrinkages [6]

### 4.2.3 Classification of Shrinkage Defects

The shrinkage defects were classified according to the area of defect

- Hub shrinkage

  Shrinkage in the hub region of the wheel around gate.

- Spoke shrinkage

  Shrinkage happens in joint area between spoke and rim.

- Rim shrinkage

  It happens in rim flange area which is the farthest from the gate.

Various parts of a wheel is shown in Figure 4.6.

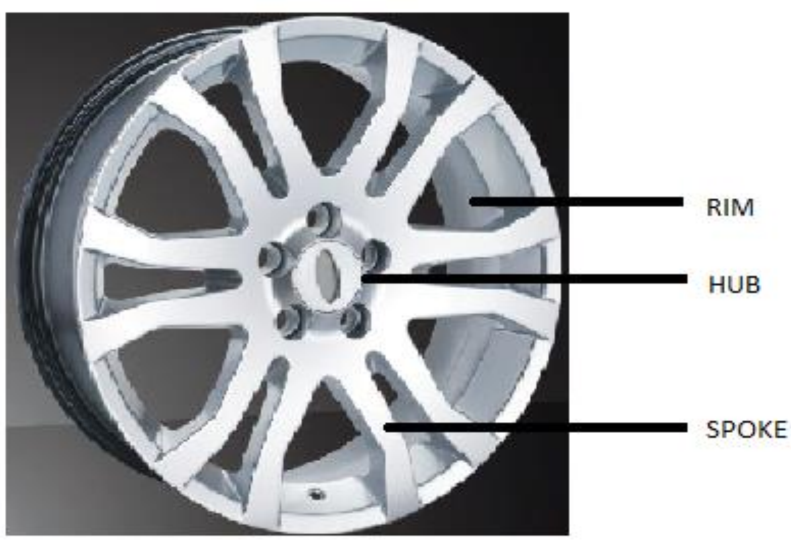


**Figure 4.6.** Wheel of an automobile [12]

Data has been collected using check sheets shown in Table 4.2. The no of rejections due to various shrinkages have been noted and is shown in pie charts shown in Figure 4.7.

**Table 4.2.** Check sheet for shrinkage defects

| M/C No | Mould | Defects | | |
| --- | --- | --- | --- | --- |
| | | Shrinkages | | |
| | | HUB | RIM | SPOKE |
| 1 | XYZ | 487 | 210 | 147 |

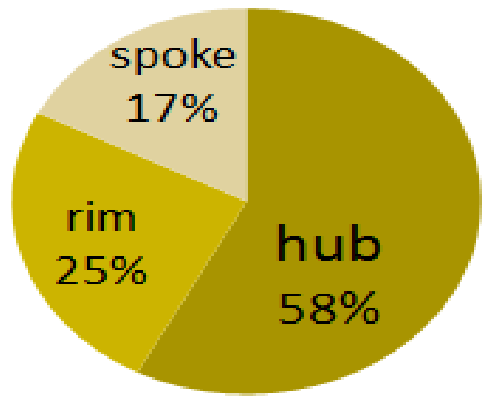


**Figure 4.7.** Pie chart for shrinkages

Using histogram as shown in Figure 4.8. It was noted that the hub shrinkages were more compared to rim and spoke shrinkages.

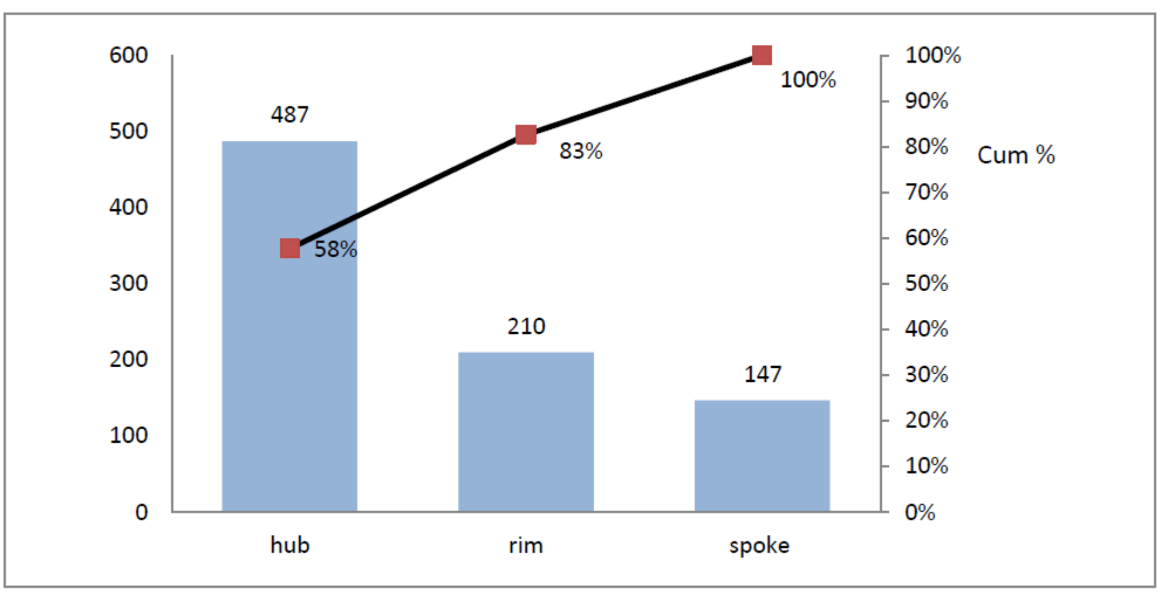


**Figure 4.8.** Histogram for shrinkage defects

## Conclusion

Hub part is the last solidified part of the wheel. Most of the shrinkages occur in the hub region due to the lack of feeding during the solidification.

**Hub Shrinkage:** It is because of in sufficient feeding of molten metal.

**Spoke Shrinkage**: It is because of formation of hot spot in the junction, where greater volume of liquid metal will flow. It may be external or internal.

**Rim Shrinkage:** It happens in rim flange area which is the farthest from the gate. It also occurs when rim thickness is less.

## Stalk

It is a refractory tube, through which the molten metal aluminum finds its way into mold cavity when holding furnace is pressurized. It is basically steel pipe as welded to a flange. The steel tube is wound with refractory material. It is fitted in to the central hole of holding furnace as shown in Figure 4.9.

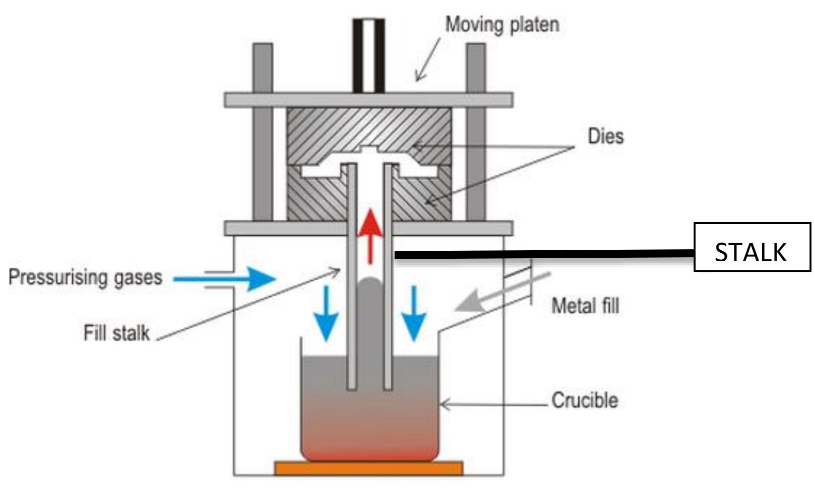


**Figure 4.9.** Low pressure die casting [13]

**Effect of Salk Change on Shrinkages**

**Observation:** The shrinkage % and the stalk changing frequency were collected. Both are related using histogram as shown in Figure 4.10.

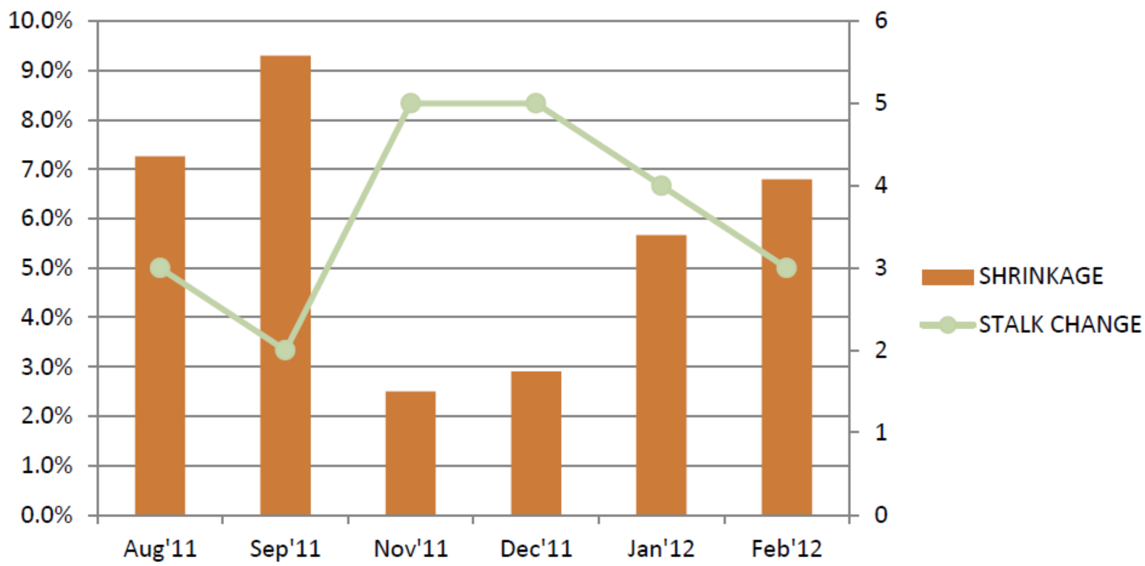


**Figure 4.10.** Histogram for stalk change & shrinkages

**Conclusion**

With the use of histograms as shown in Figure 4.10, it was noted that the shrinkage % decreases with the increase in stalk change frequency.

### 4.3 DETAILED ANALYSIS OF THE MAJOR DEFECT-CRACKS

#### 4.3.1 Cracks

The following points explain the formation of cracks

- Cracks are irregular shapes formed when the molten metal pulls itself apart while cooling in the mould or after removal from the mould as shown in Figure 4.11.
- Hot tear occurs when the crack appears during the last stages of solidification .If hot tear occurs the crack faces are usually heavily oxidized [9].
- Hot tear commonly occur in metals and alloys that have a wide freezing range, and the isolated regions of liquid become subjected to thermal stresses during cooling and fracture results.

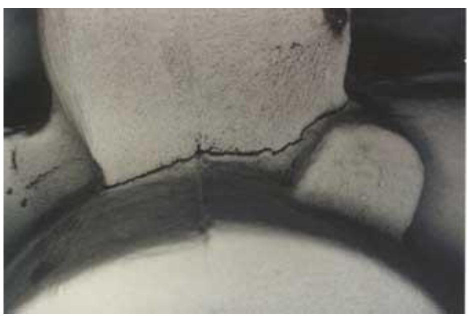

**Figure 4.11.** Crack in casting [5]

The causes for hot tearing are

• Thermal contraction

• Liquid film distribution

• Liquid pressure drop

• Vacancy supersaturation

Crack can propagate through

• Through liquid film by sliding

• By liquid film rupture

• By liquid metal embrittlement

• Depending on the temperature range it occur through liquid film or solid phase.

• It occurs when there is diffusion of vacancies from the solid to the crack.

Conditions for Formation of Crack are

• When thermal stress exceeds rupture stress of the liquid film.

• When critical value for cavity nucleation is reached when pressure drops over mush.

• When strain rate reaches a critical value and it cannot be compensated by much ductility liquid feeding [10].

- When insufficient feeding is there in the vulnerable temperature range.
- When thermal stress exceed local critical stress.
- By liquid flow and mush ductility thermal strain cannot be accommodated.

The actual hot tearing mechanism occurs on two scales:

1. Microscopic
    - Crack nucleation and propagation
    - Stress concentration
    - Structure coherency
    - Wet grain boundaries

2. Meso-Macroscopic

- lack of feeding stress
- Lack of strain or
- Strain rate imposed on the structure

The scales during equiaxed dendritic solidification is shown in Figure 4.12.

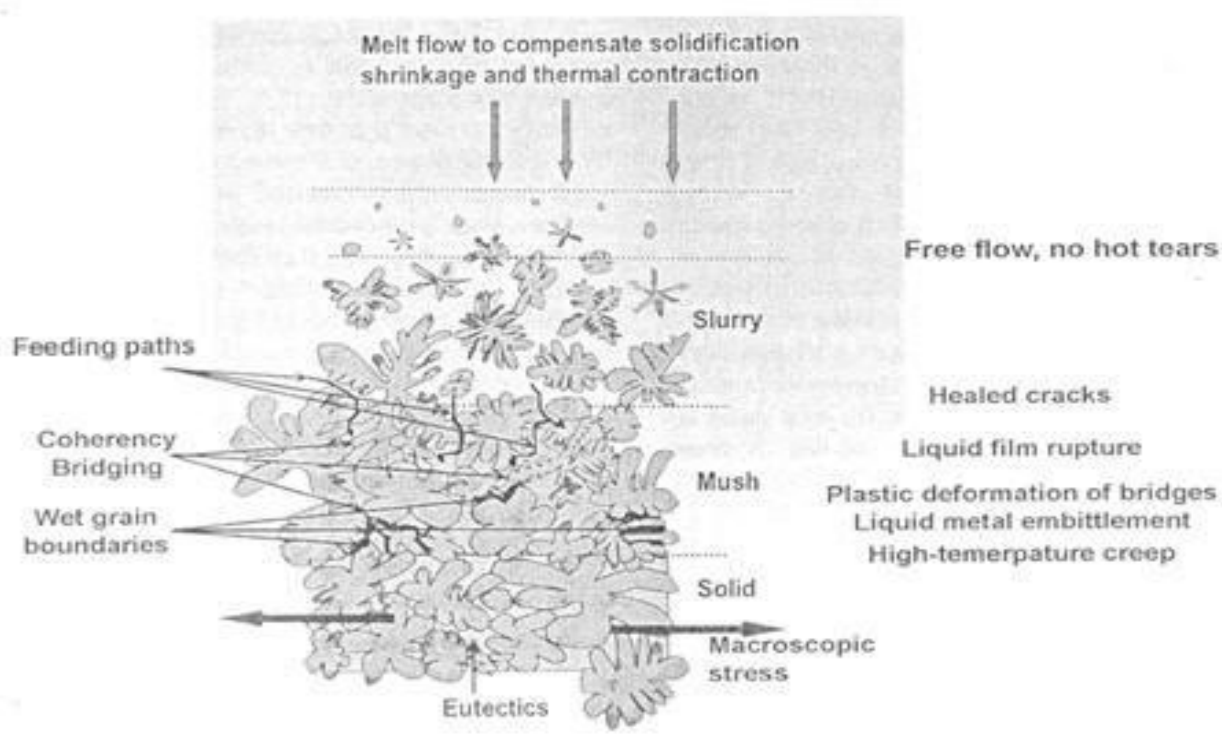


**Figure 4.12**. Different length scales of equiaxed dendritic solidification along with suggested hot tearing mechanisms [5]

Cracks mostly occur in hub region of the wheel it may internal or external. These are irregular shape cracks formed when the metal pulls itself apart while cooling in the mould or after removal from the mould.

### 4.3.2 Fish Bone Diagram for Cracks

- Cause effect diagram for cracks has been drawn and the causes for the cracks have been studied as shown in Figure 4.13.

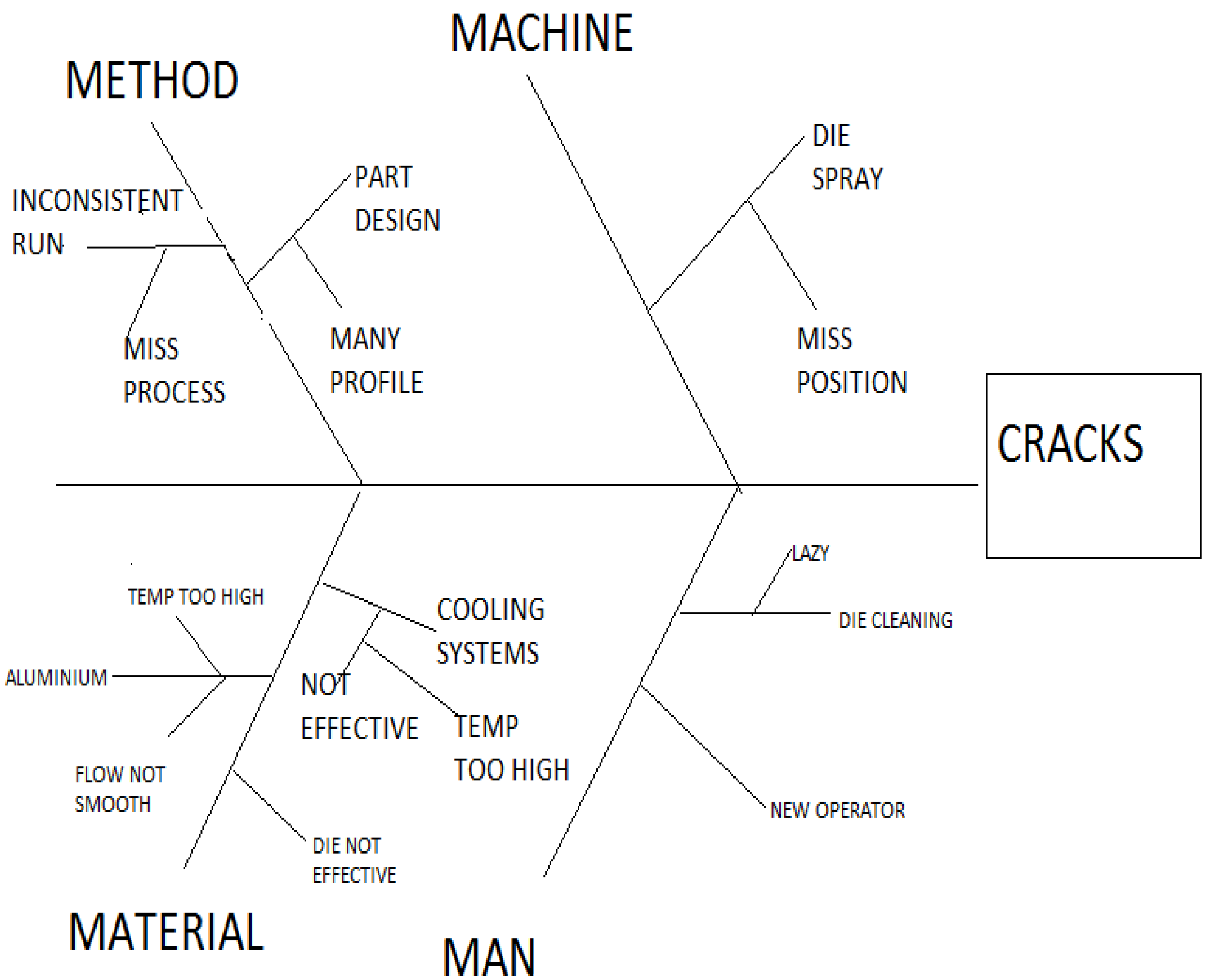


**Figure 4.13.** Cause effect diagram for cracks

## 4.4 DETAILED ANALYSIS OF THE MAJOR DEFECT-POROSITY

### 4.4.1 Porosity

The following points explain how pinhole porosity occur in castings [7]

- The main reason of gas holes and porosity defects is the trapped hydrogen gas in the molten metal during casting.
- Increase in hydrogen content will increase the porosity in the casting and the pore size.
- Main factor of gas porosity during solidification is the dissolved hydrogen level in melts and it has to be avoided otherwise it will significantly decrease the mechanical and surface finish properties of the final casting product.
- When aluminium combines with the water vapor in the atmosphere hydrogen gas is released.

$$2Al+3H_2O \rightarrow 6H+ Al_2O_3$$

- Liquid aluminium dissolves the hydrogen generated in the process.
- Solubility of gaseous hydrogen decreases when aluminum solidifies so aluminum alloys release excessive amount of hydrogen gas during Solidification from liquid state to liquid state. This results in porosity defects which distributes throughout the solid metal.
- Size of pore increases with increase in initial hydrogen content.

The following are the Sources of hydrogen in molten aluminum

- Humidity in atmosphere
- wet metallic charge
- wet furnace lining (crucible, transfer ladles)
- wet foundry instruments
- wet fluxes
- furnace fuel combustion products which contains hydrogen

**Hydrogen Concentration Measuring**

Melt quality can be known by measuring hydrogen content. The simple way of indirectly measuring the hydrogen content of the melt is to measure its specific gravity. Molten metal is collected in a sample and casted. The specific gravity is measured by weighing the sample in air and water (Archimedes Principle).

$S_g = W_a / (W_a - W_w)$

Where, $S_g$ is the specific gravity of sample.

$W_a$ is the weight of the sample noted keeping it in air.

$W_w$ is weight measured by keeping the sample in water. The volume of hydrogen can then be determined by $H_2 = (S_g - S_{gT})$ .

Where, $S_{gT}$ is theoretical specific gravity of the alloy.

### 4.4.2 Degassing

After melting the molten metal should go in to “degassing process”. In this method, an inert gas like argon or nitrogen is injected into the flow of molten metal through injection nozzles. The hydrogen diffuses into the bubbles [14]. The gas is bubbled through molten aluminum to remove absorbed hydrogen. The amount of hydrogen is reduced gradually. This bubbling action of inert gas through spinning rotor helps oxide particles to float to the surface. It also creates a large number of small bubbles of gas that are mixed with the liquid alloy. Rotory degassing method is shown in Figure 4.14.

Degassing fluxes are added to remove hydrogen from the molten metal as well as to lift oxides and particles to top of the bath so that they can be removed.

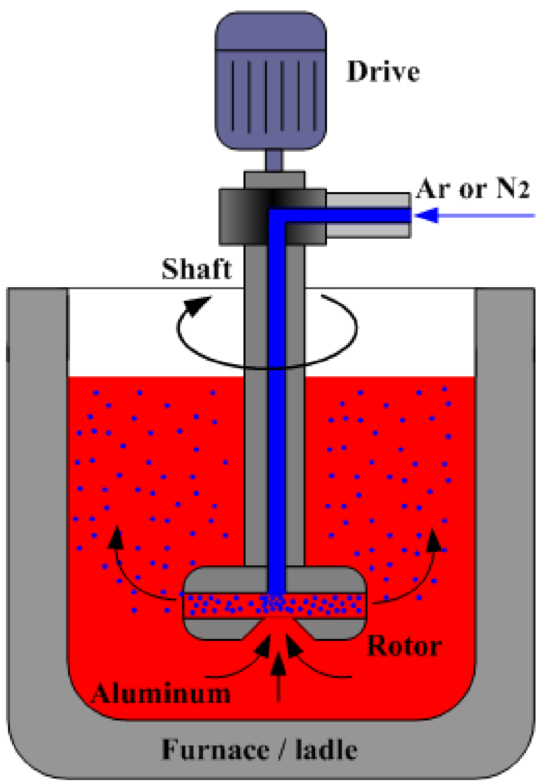


**Figure 4.14.** Rotory degassing method [14]

### 4.4.3 Porosity Control

Porosity control in aluminium castings can be done in following ways

- Hydrogen content in the molten metal decreases by increasing the degassing time.
- Degassing should be done at optimum temperature.
- The degassing should be done at lowest temperature because as the temperature increases, the volume of the gas that passes for degassing increases [6].
- The effect of molten metal temperature on specific gravity of sample for different number of samples was constructed in a graph as shown in Figure 4.15. The change of hydrogen content in the molten metal, after the application of same degassing time, with the change of metal temperature is shown in Figure 4.15.

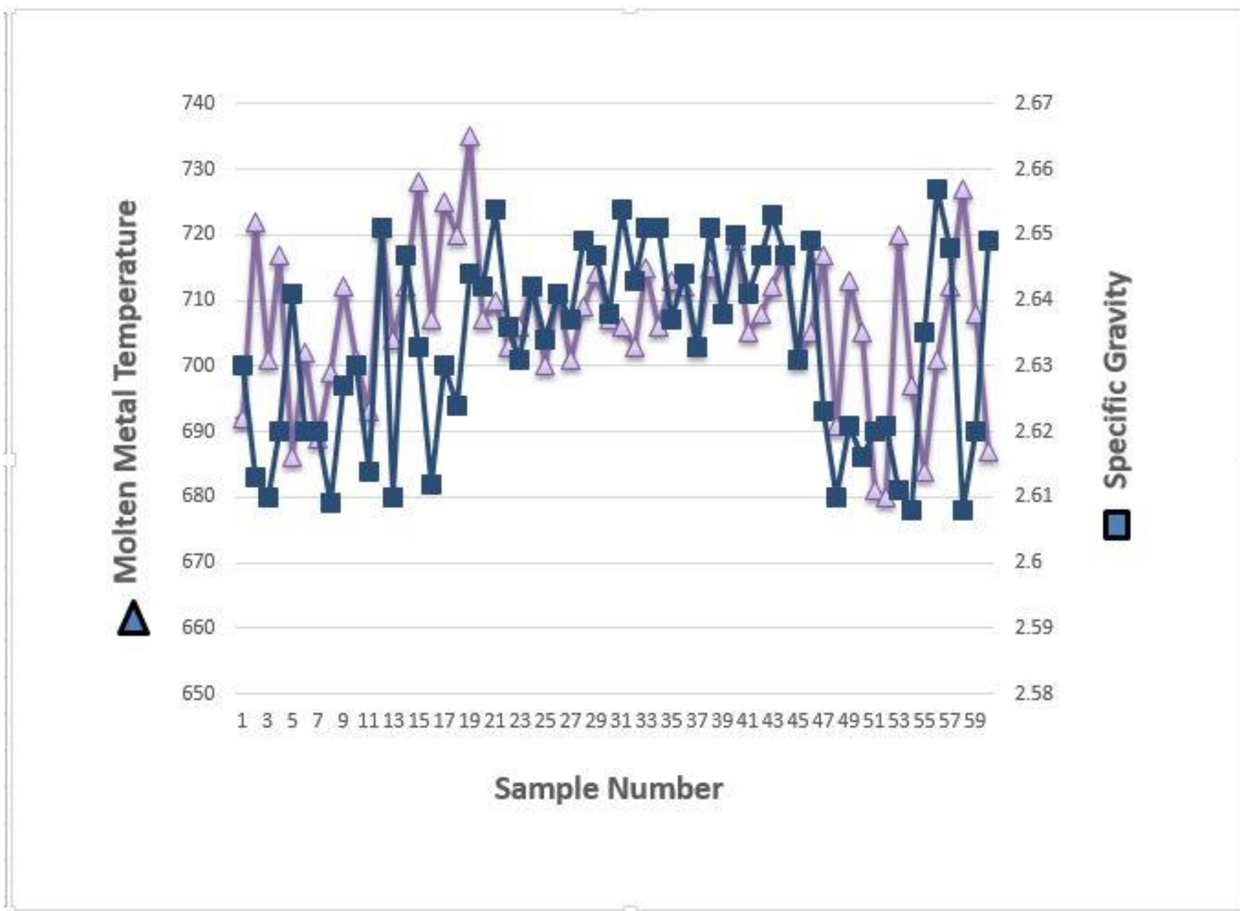


**Figure 4.15.** Effect of molten metal temperature on specific gravity of sample

The following are the results that are obtained from the graph shown in Figure 4.15.

- From sample number 1 to 20 and 45 to 60 change of the specific gravity is observed as being not in order. In these intervals, there become irregular trends for the specific gravity.
- However, between sample numbers 21and 45 the temperature from $700^0$C to $720^0$C, specific gravity regularly changes.
- Therefore, it can be said that the hydrogen content change is stable between $700^0$C and $720^0$C temperature of molten metal.
- Between these temperature limits, the specific gravity values are in the range of change between 2.63 and 2.655. In this range, there is stability in the hydrogen content of molten metal.

The following are the methods to minimize porosity defect in Aluminium alloy castings [6].

- Hydrogen content should be optimized between minimum and maximum values in order to obtain both effective feeding and low hydrogen values.
- Optimizing hydrogen content can be achieved by controlling degassing.
- Porosity can be minimized if Ti is added to the alloy as it improves grain refinement.
- By increasing degassing time provides reducing the hydrogen content to the desired levels.
- Porosity can be taken into the inside zones by applying cooling during casting in the defect occurring area so that the porosity defect on the wheel can be minimized.
- Casting temperature, casting time and casting pressure and solidification time have influences on the defects in aluminum cast wheels.
- To prevent micro porosity casting temperature has to be decreased.
- Casting pressure is outstanding for confronting the gas pore formation. Increase in casting pressure will reduce porosity.

- The solidification time affects the gas pore growth. With decreased solidification time, there becomes less time for hydrogen to diffuse from solidifying dendrite to the liquid. The formation of porosity is reduced with an increase in cooling rate.

## 4.5 DETAILED ANALYSIS OF MAJOR DEFECT- INCLUSIONS

### 4.5.1 Inclusions

Foreign particles which will not dissolve in liquid metal cause inclusions. Two types of inclusions are

I. Exogenous

II. Endogenous

- ✓ The inclusions which came from the holding furnace lining, ladle lining etc. are called exogenous inclusions.
- ✓ When the alloying element reacts with the gases present in atmosphere, gases present in the holding furnace Endogenous inclusions are formed.

$$2Al + 3H_2O \rightarrow Al_2O_3 + 6H$$

Here $Al_2O_3$ is an inclusion.

Magnesium combines with oxygen present in the atmosphere and forms oxides like MgO. These are micro sized particles which forms inclusions in the molten metal. These inclusions may reduce the ductility and also decrease the fluidity of molten metal which may of Al-Si casting alloys which may cause shrinkage defects in castings. Inclusions are nonmetallic material in a solid metallic matrix. These inclusions appear as darker or lighter indications on the radiograph as shown in Figure 4.16.

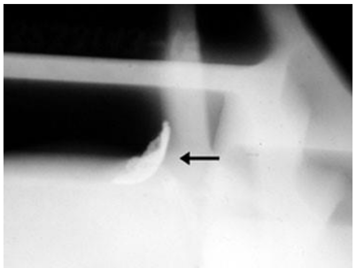

**Figure 4.16.** Inclusion [5]

### 4.5.2 Fish Bone Diagram for Inclusions

Fish bone diagram for inclusions is shown in Figure 4.17.

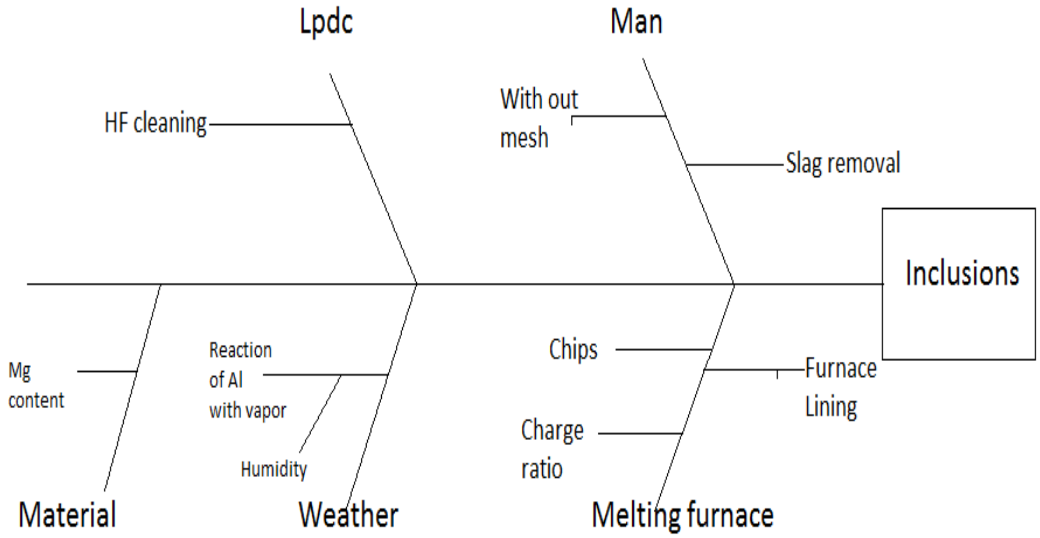


**Figure 4.17.** Fishbone diagram for inclusions

## The Holding Furnace

Inside holding furnace (HF) molten metal can be stored and can be maintained at the required temperature. It has a charging door from which molten metal is poured into the furnace. To maintain the temperature of molten metal heaters are installed at the top of the furnace. The inclusions formed inside holding furnace are to be removed frequently to minimize the inclusions in castings. Data have been collected using check sheets and the relation between HF cleaning frequency and inclusions was plotted as shown in Figure 4.18.


**Figure 4.18.** Inclusions vs HF cleaning frequency

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## Conclusion

There is significant decrease in the inclusions with an increase in the HF (Holding Furnace) cleaning frequency.

# 5. CONCLUSIONS

The correct identification of the casting defect at the initial stage is essential for taking remedial actions. This study shows the systematic approach to find the root cause of a major defects in aluminium castings using defect diagnostic approach as well as cause and effect diagram.

- Pareto diagram for defects have been drawn and the major rejections are due to shrinkages, cracks, inclusions.
- Cause effect diagrams have been drawn for shrinkages, cracks, inclusions.
- Data has been collected using check sheets and the no of rejections due to various shrinkages have been noted. Using histogram it was noted that the hub shrinkages were more compared to rim and spoke shrinkages.
- With the use of histograms it was noted that the shrinkage % decreases with the increase in stalk change frequency. A proper riser prevents shrinkage formation by maintaining a path for fluid flow. Therefore the feeding of the die is achieved by the effective riser.
- The hydrogen content change is stable between 700$^{o}$C and 720$^{o}$C temperature of molten metal. Between these temperature limits, the specific gravity values are in the range of change between 2.63 and 2.655. In this range, there is stability in the hydrogen content of molten metal.
- The relation between HF cleaning and inclusions was plotted and is concluded that there is significant decrease in the inclusions with an increase in the HF cleaning frequency. Holding furnace cleaning and removal of dross would reduce inclusions. Metal filters can be placed in gate to filter incoming molten metal.

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